

Jan. 14, 1958

L. M. FIELD

2,820,172

HIGH FREQUENCY AMPLIFYING DEVICE

Original Filed June 21, 1949

2 Sheets-Sheet 1

FIG. 2

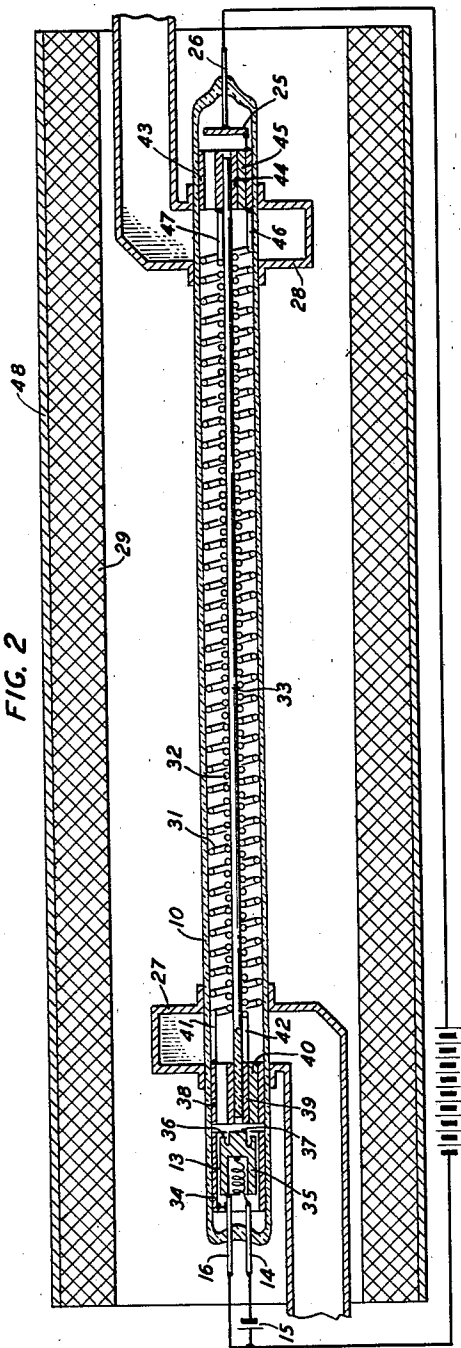
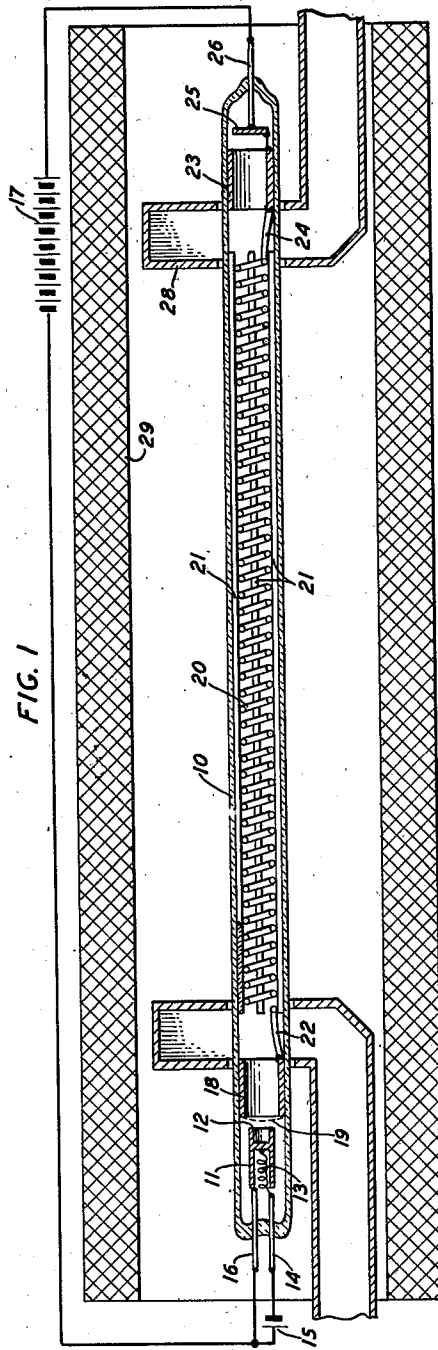


FIG. 1



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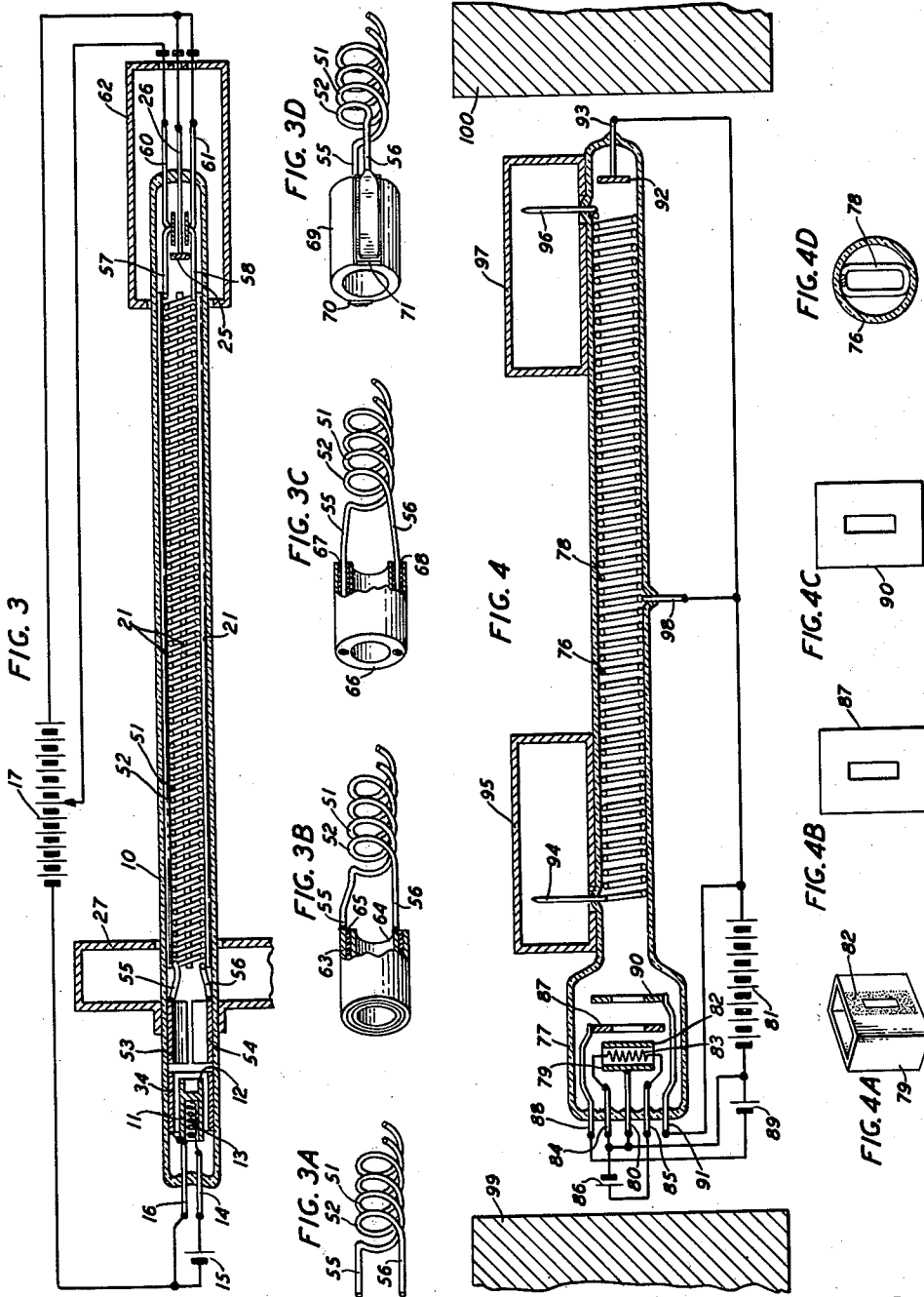
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2 Sheets-Sheet 2



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1

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HIGH FREQUENCY AMPLIFYING DEVICE

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Original application June 21, 1949, Serial No. 100,491, now Patent No. 2,725,499, dated November 29, 1955. Divided and this application April 20, 1955, Serial No. 502,556

13 Claims. (Cl. 315—3.6)

This invention relates to high frequency amplifiers which utilize the interaction between a stream of charged particles and an associated moving electromagnetic field to secure gain. Amplifiers of this general type are disclosed in the applications of J. R. Pierce, Serial No. 640,597, filed January 11, 1946 (United States Patent 2,636,948, issued April 28, 1953) and Serial No. 704,858, filed October 22, 1946 (United States Patent 2,602,148, issued July 1, 1952) and are known as beam traveling wave amplifiers.

The present application is a division of my copending application Serial No. 100,491, filed June 21, 1949 (United States Patent 2,725,499, issued November 29, 1955).

One object of the invention is to secure increased gain over that obtainable in some of the embodiments of the above-noted J. R. Pierce inventions.

A related object is to utilize more effectively the space current represented by the charged particle stream.

According to a principal feature of the present invention, the stream of charged particles which is projected to interact with a moving electromagnetic field is tubular in nature. In many embodiments of the above-noted J. R. Pierce inventions, a signal which is to be amplified is transmitted over an elongated helical conductor. The signal establishes an electromagnetic field in the vicinity of the conductor which travels lengthwise along the helix at a fraction of the velocity of light, the fraction being the ratio of the length of the helix to the length of the coiled conductor which comprises the helix. A stream of charged particles (electrons, for example) projected lengthwise of and within the field region of the helix, at a velocity approximating the forward velocity of the electromagnetic wave, imparts energy to the traveling wave, causing it to be amplified as it progresses along the helix. A tubular electron stream, it has been found, enables an energy transfer to take place which is greater than that occurring when a solid beam having the same current flow is used. The closer coupling between the electron stream and the traveling electromagnetic wave secured through the use of a tubular stream produces a correspondingly greater signal amplification. Power dissipation and beam definition difficulties which would tend to appear if the total current flow of a solid beam were increased in the hope of securing increased gain are avoided.

According to a further feature of the invention, the signal which is to be amplified is transmitted over a pair of concentric conducting helices with different radii and the electron stream is projected through the space between the helices. The electron beam is tubular in nature and one helix is within and the other without the beam. Close coupling between the traveling electromagnetic field and the tubular electron stream is obtained and high gain is available.

In accordance with a still further feature of the invention, the signal is transmitted over a pair of conducting helices having equal radii which are wound in a bifilar manner and an electron stream is projected through the common central space. The beam may be tubular in

2

nature to provide close coupling with the traveling field and the helices may be held at different direct current potentials to assist in the focusing of the beam and in the removal of noise producing positive ions.

A greater understanding of the principles involved in the present invention will be obtained from a study of the following detailed description of several specific embodiments. In the drawings:

Fig. 1 shows a beam-traveling wave tube employing a hollow cylindrical electron stream, projected within a signal conducting helix;

Fig. 2 illustrates a traveling-wave amplifier utilizing concentric helices of different radii;

Fig. 3 depicts a traveling-wave tube in which two bifilar helices are used for signal conducting purposes;

Figs. 3A, 3B, 3C, and 3D represent alternative means for coupling a signal to the bifilar helices of Fig. 3;

Fig. 4 shows a traveling-wave tube making use of a signal conducting helix of substantially rectangular cross-section, with a rectangular electron beam projected within the helix to produce gain; and

Figs. 4A, 4B, 4C, and 4D represent details of the structure shown in Fig. 4.

Referring particularly to Fig. 1, the tube shown includes an elongated glass vacuum envelope 10. Within envelope 10 near its extreme left-hand end is a thermionic cathode 11. Cathode 11 is formed of metal, is cylindrical in form, and is axially aligned with envelope 10. It has, on its right-hand end, a ring-shaped projecting portion 12 which is coated with emissive material so as to emit a tubular beam of electrons. Within the left-hand portion of cathode 11 is a heating element 13. One end of element 13 is attached to cathode 11 and the other end is connected by means of a lead 14 to one pole of a battery 15. Cathode 11 is connected to the other pole of battery 15 by a lead 16. Leads 14 and 16 pass through the left-hand end of glass envelope 10 and serve to support cathode 11. Cathode 11 is also connected through lead 16 to the negative pole of a main direct current supply source 17.

A short metal cylinder 18 is located just to the right of cathode 11. Its outer surface fits snugly against the inner surface of glass envelope 10 and a grid 19 is attached to and closes its left-hand end.

An elongated conducting helix 20 of substantially circular cross-section extends for most of the length of envelope 10. The outside diameter of helix 20 is somewhat less than the inside diameter of envelope 10 and helix 20 is supported from envelope 10 by a number of ceramic rods 21 spaced around its periphery. The left-hand end of helix 20 is located somewhat to the right of cylinder 18 and is connected to it by a short straight wire 22.

A second metal cylinder 23 is located a short distance to the right of helix 20 and is similar to cylinder 18. It is connected to helix 20 by means of a short straight wire 24.

A flat metal collector electrode 25 is situated just to the right of cylinder 23 and is connected by a lead 26 to the positive pole of direct current supply source 17. Lead 26 passes through the right-hand end of envelope 10 and holds collector 25 in position substantially at right angles to the axis of envelope 10. A short electrical connection holds cylinder 23 and collector 25 at the same potential.

Envelope 10 passes through an input wave guide 27 at that portion of envelope 10 where wire 22 connects helix 20 to cylinder 18. The axis of envelope 10 is perpendicular to the broad faces of wave guide 27. Straight wire 22 is longitudinal of envelope 10 and is parallel with the transverse electric field of guided waves of the dominant mode in wave guide 27, coupling the guide 27

and the helix 20. The right-hand end of cylinder 18 is flush with the inside surface of the left-hand wall of wave guide 27, minimizing the escape of input energy.

Farther to the right, envelope 10 passes through an output wave guide 28 with its axis normal to the broad faces of the guide 28. Straight wire 24 is similar to wire 22 in its relation to envelope 10 and guide 28 and serves to couple the guide 28 to helix 20. The left-hand end of cylinder 23 is flush with the inside surface of the right-hand wall of guide 28 to minimize the escape of output energy.

Finally, envelope 10 is surrounded throughout its length by a focusing solenoid 28 which is supplied with direct current by an appropriate source (not shown).

In the operation of the traveling-wave amplifier shown in Fig. 1, an input signal which is to be amplified is applied to input wave guide 27. Helix 20 is coupled to wave guide 27 by means of straight wire 22 and the signal is transmitted lengthwise along helix 20 at a fraction of the velocity of light, the fraction being approximately the ratio of the length of helix 20 to the length of the coiled conductor comprising helix 20.

Cathode 11 is heated by heating element 13 and a tubular stream of electrons is projected to the right from emitting portion 12. Grid 19, being positive with respect to cathode 11, serves to accelerate the electrons to the right. The electrons comprising the tubular beam travel to the right to collector 25 at a velocity approximately equal to the transmission velocity of the signal lengthwise along helix 20. The longitudinal magnetic field established by solenoid 28 prevents the electron beam from spreading to an undue extent.

The outside diameter of the tubular electron beam emitted from the coated ring-shaped portion 12 of cathode 11 is very nearly equal to the inside diameter of helix 20, the difference being many times smaller than either diameter. The thickness of the wall of the tubular beam is small in comparison with the beam diameter.

Due to the tubular shape of the electron beam, the electrons are more closely coupled to the traveling electromagnetic field set up by the transmitted signal than the electrons of a solid beam of equal space current would be. Beam definition and power dissipation difficulties which would tend to be introduced in an effort to secure increased gain merely by increasing the beam current are avoided. The electrons in the hollow beam, being closely coupled to the traveling field due to their proximity to helix 20, serve to reinforce the signal as it progresses to the right, the total gain being appreciably greater than it would be if a solid beam of the same space current were used. The amplified signal is taken off through output wave guide 28, which is coupled to helix 20 by straight wire 24.

A theoretical analysis of noise in traveling-wave tubes reveals that the noise figure can be improved by obtaining the proper relationship between the transit angles in the various parts of the electron gun or source and the other parameters of the traveling-wave tube, e. g., the gain parameter and the ratio of the electron velocity to the velocity of the wave in the absence of electrons. By way of illustration, the transit angle between surface 12 of cathode 11 and grid 19 and the transit angle between grid 19 and the point where the electrons enter helix 20 are two transit parameters of the traveling-wave tube of Fig. 1. A change in the magnitude of the electron current from cathode 11 changes the gain parameter and a change in the voltage of source 17 changes the ratio of the velocity of the electrons to the velocity of the wave in the absence of electrons. Thus, in optimizing the gain for example, tubes could be built in which the spacing between grid 19 and the beginning of helix 20 has various values. A transit angle optimum with respect to the other parameters could thereby be obtained. In general, the relation expressing the noise figure in terms of various transit angles and other parameters will be very

complicated, but in any structure such as that shown in Fig. 1 or in the figures which will be described later, a low noise figure may be achieved by varying the various physical dimensions until the best results are achieved.

Fig. 2 shows a modification of the traveling-wave tube of Fig. 1 in which a pair of concentric helices 31 and 32 with different radii are employed. Component parts corresponding to parts already described in connection with Fig. 1 have been given similar reference numerals. As in Fig. 1, the elongated evacuated envelope 10 is made of glass. Conducting helices 31 and 32 each extend for most of the length of envelope 10. The outer helix 31 is supported by envelope 10 and the inner helix 32, which has substantially the same length of conductor per unit length along the axis, to give both helices 31 and 32 substantially the same phase velocity of wave transmission, is supported by a ceramic rod 33. Helices 31 and 32 may, if desired, be wound in opposite directions.

In general, there are two modes in which energy may be propagated along concentric helices. If the coupling between helices is small and they have somewhat different velocities of propagation when uncoupled, the two modes of propagation are substantially the same as those for the two helices when separated, i. e., one is a wave on one helix, and the other is a wave on the other helix. If, however, the ratio of a parameter specifying the coupling to the fractional velocity separation is made larger, the two modes become modes in which both helices participate. One is a transverse mode in which the field mid-way between the helices is substantially transverse, and the other is a longitudinal mode in which the field mid-way between the helices is substantially longitudinal. It may be desirable to use the transverse mode to achieve a low noise figure, and it may be desirable to use the longitudinal mode to achieve maximum interaction and gain. To achieve these modes, and to assure that they have an adequate velocity separation, strong coupling between the helices is desirable. The coupling is stronger if the helices are wound in opposite directions, so that the electric and magnetic (i. e., capacitative and inductive) coupling combine additively, than it is if the helices are wound in the same direction, in which case the two types of coupling tend to cancel.

At the left-hand end of envelope 10, a short metal tube 34 surrounds a thermionic cathode 35. Metal tube 34 is supported by envelope 10 and its outside diameter is substantially the same as the inside diameter of envelope 10. Cathode 35 is cylindrical in nature and is axially aligned with envelope 10. Cathode 35 has a ring-shaped emitting surface 36 of about the same mean diameter as the mean diameter of the tubular space between the helices 31 and 32. Surface 36 is coated with electron emissive material and faces to the right.

The left-hand portion of cathode 35 is hollow and contains the heating coil 13. One side of coil 13 is connected to cathode 35 and the other side is connected through a lead 14 to one pole of a battery 15. Cathode 35 is connected to the other pole of battery 15 by a lead 16 and is also connected electrically to the surrounding metal tube 34. Cathode 35 is also connected to the negative pole of a main direct current supply source 17.

Cathode 35 has, on its right-hand end, a center circular projecting portion 37, the face of which is flush with the right-hand end of metal tube 34. Cathode 35 is held in position by leads 14 and 16, which pass through the left-hand end of envelope 10.

A pair of concentric short metal tubular members 38 and 39 are located just to the right of cathode 35 and are axially aligned with envelope 10. The outer tubular member 38 is supported by glass envelope 10 and is connected to the inner tubular member 39 by one or more metal radial fins 40. Radial fins 40 are longitudinal of envelope 10 and are spaced for minimum interference with the electron stream. Inner member 39 serves to support the left end of ceramic rod 33. Outer member 38 is connected to

the left end of outer helix 31 by a short straight wire 41, and inner member 39 is similarly connected to the left end of inner helix 32 by a short straight wire 42. Coupling wires 41 and 42 are adjusted so as to couple to and excite the desired one of the two modes of transmission of helices 31 and 32.

At the far right-hand end of envelope 10, a flat circular collector electrode 25 is held in place by a lead 26 so that the axis of envelope 10 is normal to the plane of collector 25. Lead 26 passes through the right-hand end of glass envelope 10 and is connected to the positive pole of supply source 17.

Just to the left of collector 25, a pair of tubular members 43 and 44, which correspond to members 38 and 39 at the other end of envelope 10, are connected together and held at the same potential by one or more radial metal fins 45. The outer member 43 is connected to the right-hand end of outer helix 31 by a short straight wire 46, while the inner member 44 is joined to the right-hand end of inner helix 32 by a short straight wire 47. Inner member 44 supports the right-hand end of ceramic rod 33. Outer member 43 is connected electrically to collector 25.

An input wave guide 27 is coupled to the left-hand ends of helices 31 and 32 by straight wires 41 and 42. Envelope 10 passes through wave guide 27 at that point. An output wave guide 28 is coupled to the right-hand ends of helices 31 and 32 by means of straight wires 46 and 47. Envelope 10 passes through wave guide 28 at that point. The axis of envelope 10 is substantially normal to the broad faces of wave guides 27 and 28. The right-hand ends of tubular members 38 and 39 are flush with the inside surface of the left-hand wall of input wave guide 27. Similarly, the left-hand ends of tubular members 43 and 44 are flush with the inside surface of the right-hand wall of output wave guide 28. Envelope 10 is surrounded by and is concentric with a beam focusing solenoid 28, which is furnished with direct current from a suitable source (not shown). If desired, a magnetic shield 48 may surround solenoid 28.

In the operation of the double-helix traveling-wave tube of Fig. 2, cathode 11 is heated by coil 13. Electrons emitted from emitting surface 36 are accelerated to the right by the field established by the potential difference between cathode 35 and tubular members 38 and 39, and are focused into a tubular stream by the effect of projecting portion 37 and the surrounding tubular electrode 34. The longitudinal magnetic field set up by solenoid 28 prevents the electrons from spreading as they move through the space between helices 31 and 32. Tubular electrode 34 also serves as a heat shield for cathode 35.

Helices 31 and 32 are so designed that individually each has substantially the same phase velocity of wave transmission as the velocity of electron flow established by the potential of source 17.

The signal which is to be amplified is applied to input wave guide 27 and is transmitted along helices 31 and 32. The hollow electron beam, being projected through the space between helices 31 and 32, is closely coupled to helices 31 and 32 and imparts energy to the signal wave as the signal wave travels to the right. Since one of the two helices 31 and 32 is on each side of the moving electrons, the coupling is closer than that obtainable through the use of a single helix. Available gain is correspondingly increased and the amplified signal is withdrawn from the tube through output wave guide 28.

Fig. 3 shows a modification of the traveling-wave tube of Fig. 1 using two coaxial helices 51 and 52 of the same diameter and pitch which are held at different direct current potentials to provide beam focusing action. As before, components corresponding to those previously described have been given similar reference numerals.

In Fig. 3, the elongated glass vacuum envelope 10 has a thermionic cathode 11 situated at its left-hand end. Cathode 11 is similar to that described with reference to

Fig. 1. It has a ring-shaped emitting surface 12 facing to the right and is heated by an internal heating coil 13. Coil 13 receives power from a battery 15 and cathode 11 is supported by a pair of leads 14 and 16 which also connect battery 15 to coil 13. Cathode 11 is also connected to the negative pole of a direct current power supply 17. A tubular focusing electrode 34 surrounds and is coaxial with cathode 11 and is supported by glass envelope 10. Electrode 34 is electrically connected to cathode 11.

Helices 51 and 52 extend for most of the length of envelope 10 and are interwound in a bifilar manner. They are supported from glass envelope 10 by several ceramic rods 21 spaced around the inside of envelope 10.

A slit metal tubular member is located just to the right of cathode 11 and is composed of an upper section 53 and a lower section 54. Sections 53 and 54 are supported by glass envelope 10. The right-hand end of upper section 53 is connected by a short length of relatively straight wire 55 to the left-hand end of helix 51 and the right-hand end of lower section is connected by a short straight wire 56 to the left-hand end of helix 52.

Near the right-hand end of envelope 10, helices 51 and 52 are connected by a pair of curved wires 57 and 58 to respective plates of a radio frequency by-pass condenser 59. If desired, dielectric material may be employed between the plates of condenser 59. Curved wire 57 is connected to a lead 60 which is brought out through the right-hand end of glass envelope 10 and connected to a variable intermediate tap on direct current supply source 17. Similarly, curved wire 58 is connected to a lead 61 and lead 61 is brought out through the right-hand end of envelope 10 and connected to the most positive pole of supply source 17.

A collector 25 is located just to the left of condenser 59. Collector 25 is flat and the axis of envelope 10 is normal to its plane. Collector 25 is supported by a lead 26 which is curved around the structure of condenser 59 and which extends out through the right-hand end of envelope 10. Lead 26 is also connected to the most positive pole of direct current source 17.

Envelope 10 passes perpendicularly through an input wave guide 27 at the left-hand end of helices 51 and 52, which are coupled to guide 27 by straight wires 55 and 56. The right-hand ends of sections 53 and 54 are flush with the inside surface of the left-hand wall of input guide 27. Beyond the right-hand end of helices 51 and 52 envelope 10 extends into an output wave guide 62. Output wave guide 62 is normal to the plane of the paper in Fig. 3 and is closed at one end. The connections from leads 26, 60 and 61 are brought out through the right-hand wall of wave guide 62 in an appropriate manner and the loop formed by curved wires 57 and 58 and condenser 59 couples the output of helices 51 and 52 magnetically to wave guide 62.

When cathode 11 is heated by coil 13, a hollow cylindrical stream of electrons is projected to the right. The potential difference between helices 51 and 52 focuses the electrons into the tubular beam and prevents them from spreading, enabling bulky external focusing means to be dispensed with. When an input signal is applied to wave guide 27, an electromagnetic wave is caused to travel to the right along helices 51 and 52. The tubular electron beam is closely coupled with the traveling wave and reinforces it in the course of its travel. The mean speed of the electrons through the helix structure is determined by the approximate mean between the voltages on leads 60 and 61 and is chosen to correspond to the phase velocity of wave propagation lengthwise along the helix structure. Amplified signal energy is withdrawn at the right-hand end of helices 51 and 52 through output wave guide 62. In addition to its beam focusing action, the potential difference between helices 51 and 52 tends to remove positive ions from the electron path, enabling random ion noise to be reduced.

If it is desired to employ a solid electron beam in-

stead of a tubular one, the ring-shaped projection 12 on cathode 11 may be eliminated and the entire right-hand surface of cathode 11 coated with electron emissive material.

In Fig. 3, two structures for coupling the bifilar helices 51 and 52 to a wave guide are shown, one in connection with input wave guide 27 and the other in connection with output wave guide 62. A simple alternative is shown in Fig. 3A. There, assuming the coupling to be to input guide 27, straight wires 55 and 56 merely project longitudinally from the left-hand ends of helices 51 and 52, respectively, as probes, part way into guide 27.

Fig. 3B shows another coupling arrangement which may be used to advantage. In Fig. 3B, a pair of concentric metal tubular members 63 and 64 are separated by an insulating tube 65. The two tubular members 63 and 64 form a by-pass condenser and assure that there will be no radio frequency voltage between the ends of wires 55 and 56. As applied to the signal input circuit of Fig. 3, the outer tubular member 63 is positioned as are members 53 and 54 and is supported by glass envelope 10. Wire 55 connects helix 51 to the right-hand end of outer member 63, and wire 56 connects helix 52 to the right-hand end of inner member 64. Insulating tube 65 may be, for example, mica or ceramic.

Another coupling structure appears in Fig. 3C. There, a short metal tubular member 66 is of such size as to fit snugly within the glass envelope 10 of Fig. 3. Two holes are bored lengthwise of the tube in the wall of member 66 diametrically opposite each other. Inside the holes are respective sections of insulating tubing 67 and 68. Wire 55 extends from the left-hand end of helix 51 into insulating tube 67, while wire 56 extends from the left-hand end of helix 52 into insulating tube 68. Tubular member 66 is likewise positioned as are members 53 and 54 in Fig. 3.

Still another coupler is shown in Fig. 3D. In that figure, two diametrically opposite portions of the outer surface of a metal tubular member 69, which is located in a position corresponding to that of members 53 and 54 in Fig. 3, are flattened somewhat. Mica strips 70 and 71 are applied to the respective flattened portions. The left-hand end of wire 55 is flattened and attached to mica strip 70 and the left-hand end of wire 56 is flattened and attached to mica strip 71.

The couplers shown in Figs. 3B, 3C, and 3D have the advantage of presenting an axially symmetrical direct current electric field to the electron stream by the respective tubular members. They also tend to avoid possible beam defocusing troubles.

In the traveling-wave tubes described above, helices of substantially circular cross-section have been used. Under some circumstances, it may be desirable to employ helices of other than circular cross-section in order to get the wire of the circuit closer to the electron stream and thereby increase available gain. Fig. 4 shows a modification of the traveling-wave tube of Fig. 1 using a substantially rectangular electron stream and a helix of substantially rectangular cross-section.

The tube structure shown in Fig. 4 is largely housed in an elongated glass vacuum envelope 76, the left-hand end 77 of which is of somewhat enlarged cross-section. A metal helix 78 of substantially rectangular cross-section is supported by glass envelope 76 and extends for most of its length. A metal cathode 79 is located within the enlarged portion 77 of envelope 76 at the left-hand end of envelope 76. Cathode 79 is in the form of a hollow rectangular box, with the axis of envelope 76 normal to the surfaces of the box having the greatest area. The box is open at the top and bottom and is held in place by a lead 80 which extends through the left-hand end of envelope 76 and which is, in turn, connected to the negative pole of a direct current supply source 81. A detail of cathode 79 is shown in Fig. 4A. The right-hand face of cathode 79 is coated with electron

emissive material 82. Emissive material 82 is arranged to emit a hollow electron beam of rectangular cross-section lengthwise of and within helix 78.

A heating coil 83 is located within the hollow interior of cathode 79 and is held in place by a pair of leads 84 and 85 extending through the left-hand end of envelope 76. Leads 84 and 85 are connected to the negative and positive poles, respectively, of a battery 86. Lead 84 is also connected to the negative pole of supply source 81.

A modulator electrode 87, in the form of a flat metal plate with a rectangular aperture, is located just to the right of cathode 79. Its aperture is aligned with emissive material 82 and it is held in place by a lead 88 which is brought out through the left-hand end of envelope 76. Lead 88 is connected to the negative pole of a battery 89, the positive pole of which is connected to the negative pole of direct current source 81. A view of modulator electrode 87 is shown in Fig. 4B.

An accelerator electrode 90 is located just to the right of modulator electrode 87, and is held in place by a lead 91 which extends through the left-hand end of envelope 76. Accelerator electrode 90 is similar to modulator electrode 87, being also a flat metal plate with a rectangular aperture. Its aperture is aligned with that of modulator electrode 87. Lead 91 is connected to the most positive pole of direct current supply source 81. A more detailed view of accelerator electrode 90 is shown in Fig. 4C. Cathode 79, modulator electrode 87, and accelerator electrode 90 are all located in the enlarged left-hand portion 77 of envelope 76.

A collector 92 is located at the extreme right-hand end of envelope 76, and comprises a round metal plate which is at right angles to the axis of envelope 76. Collector 92 is held in place by a lead 93, which is brought out through the left-hand end of glass envelope 76 and connected to the positive pole of supply source 81.

As has been previously noted, helix 78 is substantially rectangular in cross-section and is supported by glass envelope 76. A section view of the elongated portion of envelope 76 containing helix 78 is shown in Fig. 4D.

The left-hand end of helix 78 is sealed through envelope 76 and projects as an antenna 94 into an input wave guide 95. As shown in Fig. 4, input wave guide 95 is normal to the plane of the paper. It is closed at one end and connected to a signal source at the other. The right-hand end of helix 78 is similarly sealed through envelope 76 and projects as an antenna 96 into an output wave guide 97. Output guide 97, normal to the plane of the paper, is closed at one end and connected to a load at the other.

Approximately mid-way along the length of helix 78, the inside surface of envelope 76 is coated with lossy material which serves to separate helix 76 electromagnetically into two portions. At the center of lossy region, helix 76 is connected by means of a lead 98 to the positive pole of direct current source 81. Lead 98 is taken out through the wall of envelope 76.

A pair of pole-pieces 99 and 100 of an electromagnet are located at either end of envelope 76 and provide an axial magnetic focusing field.

When cathode 79 is heated by heating coil 83, electrons are projected lengthwise of and within helix 78 in the form of a hollow rectangular beam. Modulator electrode 87 serves to control and focus the electrons making up the beam. Accelerator electrode 90 serves to accelerate and further focus the beam.

When a signal is applied to input wave guide 95, it is transmitted along helix 78 at a forward velocity approximately equal to the velocity of the electrons in the beam. The projected electrons traveling in the tubular beam are closely coupled to the traveling electromagnetic field set up by the applied signal and impart energy to it. The amplified signal is taken off through output wave guide 97 and the electrons passing through helix 76 are collected on collector 92.

If it is desired to use a solid rectangular beam instead of a hollow one, the electron emissive coating 82 on the right-hand side of cathode 75 may be so formed.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A space discharge device which utilizes the interaction between a traveling electromagnetic wave and a stream of charged particles for amplifying the wave comprising a wave transmission line for propagating a traveling electromagnetic wave including a pair of conductors in the form of interwound elongated coaxial helices of substantially equal transverse dimensions extending over the same portion of said path, said helices being in a bifilar relation, and means for projecting a stream of charged particles lengthwise of said helices and within the field region of the wave propagating therealong.

2. The space discharge device in accordance with claim 1 in which said stream is tubular, thereby producing close coupling between said stream and said helices.

3. A space discharge device in accordance with claim 1 including circuit means for holding said helices at different D.-C. potentials for focusing the charged particle stream.

4. A high frequency amplifier which utilizes the interaction between a traveling electromagnetic wave and a stream of charged particles for amplifying the wave comprising a wave transmission circuit for propagating a traveling electromagnetic wave including a pair of conductors in the form of interwound elongated helices of substantially circular cross-section and substantially equal radii extending over the same portion of the wave transmission path, said helices being in a bifilar relation, and means for projecting a stream of charged particles lengthwise of said helices and within the field region of the wave propagating therealong.

5. A high frequency amplifier in accordance with claim 4 including circuit means for holding said helices at different D.-C. potentials, whereby a focusing effect is produced upon said stream.

6. A wave amplifying device which utilizes the interaction between a traveling electromagnetic wave and a stream of charged particles for amplifying the wave comprising a transmission line for propagating a traveling electromagnetic wave including a pair of conductors in the form of interwound elongated coaxial helices of substantially circular cross-section and substantially equal radii extending over the same portion of said path, said helices being in a bifilar relation, circuit means for holding said helices at different D.-C. potentials, a signal input circuit coupled to both of said helices at one end of said path, a signal output circuit coupled to said helices at the other end of said path, and means for projecting a stream of charged particles lengthwise of and within said helices.

7. A microwave amplifying device which utilizes the interaction between a traveling electromagnetic wave and a stream of charged particles for amplifying the wave which comprises at least two interwound coaxial wire helices of substantially equal radii extending over the same portion of a wave transmission path for propagating a traveling electromagnetic wave, said helices being in substantially a multifilar relation with one another, a source of charged particles, means to direct a stream of charged particles from said source lengthwise of and within the combined field region of said helices, input coupling means in energy transfer relation with the upstream end of at least one of said helices for supplying thereto signal waves to be amplified, and output coupling means in energy transfer relation with the downstream end of at least one of said helices for withdrawing therefrom the amplified signal waves.

8. A microwave device which utilizes the interaction between a traveling electromagnetic wave and a stream of charged particles for amplifying the wave comprising means defining a path of travel for electrons, electrode means to direct a stream of electrons lengthwise substantially from one end to the other of said path, and an elongated electromagnetic wave transmission circuit for propagating a traveling electromagnetic wave which includes a pair of substantially coaxial interwound helical conductors of substantially equal radii extending together along at least a major portion of said path, each of said helical conductors extending over substantially the same portion of said path, said helical conductors being in substantially a bifilar relation with each other, and said helical conductors being disposed with at least a major portion of the path of the electron stream included within their combined field region.

9. In a device which utilizes the interaction between an electron stream and a traveling electromagnetic wave, means defining a path of electron flow, and an interaction circuit adjacent said path of flow for propagating a traveling electromagnetic wave in coupling proximity with said electron flow for a plurality of operating wavelengths, said interaction circuit comprising two helical conductors having equal pitches and radii and being interwound to form a bifilar helix, said bifilar helix being positioned along a major portion of the length of said path of electron flow.

10. In a device which utilizes the interaction between an electron stream and a traveling electromagnetic wave, means defining a path of electron flow, and an interaction circuit adjacent said path of flow for propagating a traveling electromagnetic wave in coupling proximity with said electron flow, said interaction circuit comprising two helical conductors having equal pitches and radii and being interwound to form a bifilar helix, said bifilar helix being positioned to surround the path of electron flow along a plurality of operating wavelengths and extend along the major portion of its length.

11. In a device which utilizes the interaction between an electron stream and a traveling electromagnetic wave, means defining a path of electron flow, an interaction circuit adjacent said path of flow for propagating a traveling electromagnetic wave in coupling proximity with said electron flow, said interaction circuit comprising two helical conductors having equal pitches and radii and being interwound to form a bifilar helix, said bifilar helix being positioned along a major portion of the length of said path of electron flow, and means for maintaining the two conductors of said bifilar helix at different electrical potentials.

12. In a device which utilizes the interaction between an electron beam and a traveling electromagnetic wave, an interaction circuit comprising two helical conductors having equal pitches and radii and being coaxially disposed and interwound to form a bifilar helix, said bifilar helix characterized by having its successive turns spaced apart to form a continuous helical wave path of the spacing along the length of the bifilar helix for propagating a traveling electromagnetic wave therealong, a component of the electric field of said wave having a predetermined axial phase velocity, and means for projecting lengthwise of said bifilar helix and within the field region of said wave energy a stream of electrons having an average velocity approximately equal to the axial phase velocity of said component of electric field.

13. In a device which utilizes the interaction between an electron beam and a traveling electromagnetic wave, an interaction circuit comprising two helical conductors having equal pitches and radii and being coaxially disposed and interwound to form a bifilar helix, said bifilar helix characterized by having its successive turns spaced apart to form a continuous helical wave path of the spacing along the length of the bifilar helix for propagating a traveling electromagnetic wave therealong, a component of the electric field of said wave having a predetermined

11

axial phase velocity, and means for projecting lengthwise of said bifilar helix and within the field region of said wave energy a stream of electrons having an average velocity approximately equal to the axial phase velocity of said component of electric field, and coupling means located at one end of said bifilar helix in coupling relation therewith.

5

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